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14. ABSTRACT

In wireless sensor networks, relay transmissions can enable cooperative diversity by forming virtual antenna arrays. The optimum resource allocation in such systems is critical to enhance their error rate performance and energy efficiency. Existing work often focus on the optimization of the energy allocation among the source and relay nodes. This is not only undesirable from the relays' point of view especially when they are required to transmit at high power levels, but also impossible at times since the sensor nodes are each limited by their individual battery capacity. On the other hand, the source is very likely to have multiple candidates to choose from. In a mobile sensor network, the relay nodes can also move to desirable locations to better assist the communication from the source node to the destination node. In order to exploit the freedom in terms of relay location, we treat the resource allocation in relay networks as a two-dimensional (energy and location) optimization problem and establish some very interesting results. To facilitate the implementation of such an optimum strategy, we also investigated precise localization techniques for wireless sensor networks.

15. SUBJECT TERMS

wireless sensor networks, wireless cooperative networks, resource optimization, ultra-wideband, localization, ranging

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FY07 Year End Report

WIRELESS COOPERATIVE NETWORKS: SELF-CONFIGURATION AND OPTIMIZATION

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A Abstract

In wireless sensor networks, relay transmissions can enable cooperative diversity by forming virtual antenna arrays. The optimum resource allocation in such systems is critical to enhance their error rate performance and energy efficiency. Existing work often focus on the optimization of the energy allocation among the source and relay nodes. This is not only undesirable from the relays' point of view especially when they are required to transmit at high power levels, but also impossible at times since the sensor nodes are each limited by their individual battery capacity. On the other hand, the source is very likely to have multiple candidates to choose from. In a mobile sensor network, the relay nodes can also move to desirable locations to better assist the communication from the source node to the destination node. In order to exploit the freedom in terms of relay location, we treat the resource allocation in relay networks as a two-dimensional (energy and location) optimization problem and establish some very interesting results. To facilitate the implementation of such an optimum strategy, we also investigated precise localization techniques for wireless sensor networks.

B Technical Results

We consider two prevalent relay protocols for wireless sensor networks: decode-and-forward and amplify-and-forward. To alleviate the channel estimation load at the receiver side, we consider differential modulation and demodulation for both protocols. We derive a tight upper bound of the error performance for the decode-and-forward case and a close approximation of the error performance for the amplify-and-forward case. Both are simple closed-form expressions accounting for arbitrary number of relays and possible existence of a direct wireless link from the source node to the destination node.

Based on these closed-form expressions, we then establish the optimum energy allocation strategy at the source and relay nodes given any source-relay-destination distances, and the optimum relay location selection for any energy distribution at the source and relay nodes. On top of these uncoupled optimizations, our error performance bound and approximation also allows for numerical search (as opposed to extensive simulations) of the global optimum operation condition which maximally reduces the total energy consumption or extends the communication range.

Our extensive analytical and simulated comparisons confirm that the optimized systems provide considerable improvement over un-optimized ones. We also show that the relay location optimization, which has been long neglected in related studies, may be more critical than the energy optimiza-

tion. In addition, our joint optimization often results in considerably reduced power consumption at the relay nodes. This is favorable to wireless sensor networks where each node may have its own sensing data to transmit, since they can maximally conserve energy when helping others as relays.

To enable the implementation of such an optimum strategy in wireless sensor networks, the sensor nodes need to know their precise (absolute or relative) locations. In the past, the Global Positioning System (GPS) has been the major method for wireless localization and navigation. However, its application is constrained since the GPS signal is not available in indoor, metropolitan and heavy-foliage scenarios which, more often than not, are where the sensor networks are deployed. Therefore, we need to exploit alternative terrestrial wireless signals for positioning and navigation. In our work, we consider both the ultra-wideband (UWB) signals that are intentionally set up, and the wireless local area network (WLAN) IEEE 802.11a/g signals that are widely available and are known as the "signal-of-opportunity." For both signals, we investigate the time-difference-of-arrival (TDoA) based ranging and localization.

The Cramer-Rao Bound (CRB) analysis shows that UWB signals can provide high resolution timing and positioning, thanks to its huge bandwidth. However, in practical implementation, the CRB can not be achieved because the perfect channel information may not be available at the receiver. To this end, we investigate how to exploit the huge bandwidth for high resolution ranging in practical scenarios. We compare the coherent and noncoherent combining of the multi-band signals for ranging. The comparisons show that a high timing resolution can be achieved by combining the channel information from multiple sub-bands in a coherent manner. However, when the channel is independent across sub-bands, the multi-band signals can only be combined in a noncoherent manner to improve the mis-timing performance. In particular, the slope of the probability of mis-timing curve becomes steeper as the number of sub-bands increases. This is reminiscent of the concept of diversity known in communications.

We also propose a simple model-based time-of-arrival (ToA) estimation approach. In this approach, the channel impulse response (CIR) is recovered with a simple equally-spaced model. Then, the delay of channel path is estimated by minimizing the energy leakage from the first path. Compared with the widely adopted space alternating generalized expectation maximization (SAGE) algorithm, our model-based approach has the advantage of lower complexity while providing similar or better ranging performance. Based on this ToA estimator, we realize the TDoA-based and TDoA-Doppler hybrid localization algorithms. Simulations are also carried out to corroborate our theoretical analysis.

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